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FOSTERING INNOVATION THROUGH ROBOTICS EXPLORATION

CARNEGIE MELLON UNIVERSITY

JUNE 2015

FINAL TECHNICAL REPORT

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This effort enhanced Robotics STEM activities by incorporating Cognitive tutors at key points to make important mathematical decision or implement critical calculations. Program utilized Cognitive Tutor Authoring tools for designing problem solving tasks, establishing prototypical solutions, reasoning about solution steps, and cognitive models. The project developed new technologies designed to increase students computational and algorithmic thinking. The project targets both formal and informal education. The developed Computer Science Student Network (CS2N) www.cs2n.org teaches multiple aspects of computer science in scaffolded ways that students and teachers will find engaging. In Phase One the effort developed the following new technologies: Robot Virtual World Software the architecture that enables us to go to scale. In phase two the effort harden and iteratively improve the architecture. A significant new addition to the research goals was the inclusion of student and teacher badges.

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1.0 Summary

This effort enhanced Robotics STEM activities by incorporating cognitive tutors at key points to make important mathematical decision or implement critical calculations. The program utilized Cognitive Tutor Authoring tools for designing problem solving tasks, establishing prototypical solutions, reasoning about solution steps, and cognitive models. The project developed new technologies designed to increase students computational and algorithmic thinking. The project targeted both formal and informal education. The developed Computer Science Student Network (CS2N) teaches multiple aspects of computer science in scaffold ways that students and teachers will find engaging.

2.0 Introduction

The Computer Science Student Network (CS2N) was funded by DARPA using Air Force Research Laboratory Award FA8750-10-2-0165. The project's goal is to significantly increase the number of students studying Computer Science – Science, Technology, Engineering and Mathematics (CS-STEM). The project is the result of CMU's Fostering Innovation through Robotics Exploration (FIRE) project. The project is housed are Carnegie Mellon University's Robotics Academy and uses the Robotics Academy's influence in the Robotics Education community to market CS-STEM activities nationally.

3.0 Project Goals - Fostering Innovation through Robotics Explorations (FIRE)

Figure 1 provides the stated goal for the Fostering Innovation through Robotics (FIRE) project; "*Inspire 1M students per year to pursue advanced CS-STEM careers*." Based on formal and informal education adoption of FIRE technologies the project can claim that it is reaching nearly 1 million children per year. FIRE inspired curriculum and software is being used in over 10,000 formal and informal education environments. Robot Virtual World software has been downloaded over 100,000 times, has been purchased by over 1,000 schools, and is growing in popularity with the Robotics Competition Community which has over 35,000 US teams.

FIRE technologies have been studied in classroom environments and have proven to significantly increase mathematical abilities in children (Expedition Atlantis Study) and improve the rate children learn to program robots by 60% (Robot Virtual World Study). There is still much work to do to improve adoption as well as efficacy, but project technologies have been successfully implemented and proven to be effective in formal and informal education settings.

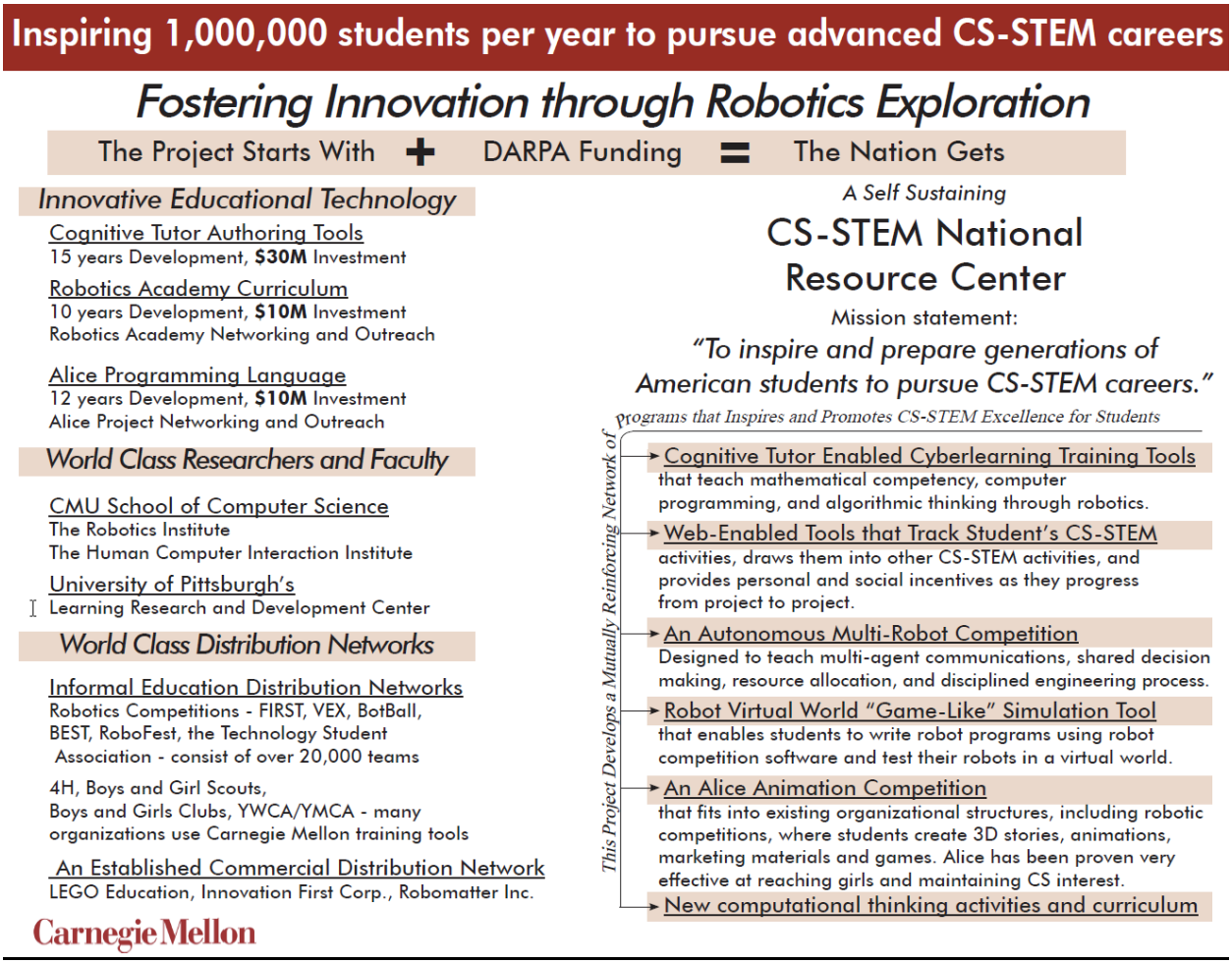

Figure 1 - Project Goal

4.0 FIRE became the Computer Science Student Network

The Computer Science Student Network (CS2N), depicted in Figure 2, is an online aggregator of robotics and computer science related activities. CS2N's project design starts with activities in informal education like: robotics competitions, Boy Scout merit badges, and 4H robotics. Carnegie Mellon has iteratively improved these robotics technologies, aligned them with standards, developed teachers' guides, and made them available to formal and informal education.

Figure 2. Computer Science Student Network

5.0 Lessons Learned - FIRE's Proudest Accomplishments

The project developed a robotic simulation environment that enables children and schools without physical robots to learn programming. The simulation environments are programmable using LEGO NXT-G, LEGO EV3, LabVIEW, and ROBOTC software and LEGO NXT, TETRIX, EV3 and VEX Cortex and VEXIQ robots; these are the dominant software and hardware environments found in classrooms today. Carnegie Mellon Robotics Academy (CMRA) will continue to study and iteratively improve on these "game changing" technologies since they have been found to be an effective way to teach computational thinking and are orders of magnitude less expensive that their physical counterparts.

The Expedition Atlantis math game – The Expedition Atlantis (EA) game was developed to replace the Robotics Flash-based Cognitive Tutor when the project team determined that

the limitations of a Flash-based development environment would limit the scalability of our new robot-math focused training materials. EA is developed using Unity, a game developments software, that is compatible with iPads, Android devices, PCs and MACs. EA testing in classrooms found that when properly implemented robotics can be used to teach mathematics. EA in now available on iPads in the form of an app, the game is fun to kids, and EA is part of CS2N's long term sustainability plan.

The development of a cloud-based aggregator, CS2N that enables project staff to: offer online training, collect data, enables teachers to setup classes, offers automatic assessment in the form of badges, and enables all stakeholders to track students' progress through either CS2N or the student's local computer. CS2N will enable CMRA to continue to conduct research on new educational technologies that it develops.

The development of teacher and student certifications. Over the life of the FIRE project CMRA project staff developed a data bank of assessment questions that aligned with the competencies taught in a college entry-level computer science course. Those questions, along with additional robotics questions enabled the project to develop a Robotic Educator's Certification (REC) for the LEGO and VEX hardware platforms. The certification test measures content knowledge as well as a teacher's pedagogical abilities. At the end of teacher training the teacher takes the REC test. If the teacher passes the REC test, they receive a REC that certifies that they have the skills to teach robotics at the middle or high school level.

The ability to offer free training through multi-media developed. Highly scaffold curriculum which was developed with FIRE (and other) funding. The ongoing development of free Moodle Based courses that are used by students every day. CS2N supports thousands of students and teachers competing in robotics competitions each robotic competition season.

CMRA was able to leverage DARPA funding to secure DML funding, NSF funding, and corporate.

CMRA has a sustainability plan that will leverage DARPA funding to sustain CMRA outreach for the foreseeable future (which was a significant DARPA requirement).

6.0 Lessons Learned FIRE's Biggest Disappointments

The project staff initially decided to develop training materials around a Flash-based Cognitive Tutor (CT) that is no longer being used because Flash is not supported by iPads.

The good news is the demise of Flash pushed us toward game development software and that the lessons learned during the development of the CT transferred into the new game.

That the project has developed incredible educational technologies like:

a. A cloud-based multi-robot online robotics competition that will enable kids from schools across the country to compete virtually;
b. A robot transformer that could enable students to import their own custom robots into the robot simulation environment;
c. Automated assessment tools designed to help teachers to understand what children know or don't know;
d. And, a cloud-based computer science/math game that shows significant mathematical learning gains in testing, and leads into CS programming, that needs extension activities as well as further testing to improve its efficacy in formal and informal settings.

Research shows that these technologies show incredible promise, but CMRA doesn't have the funding to complete the research and development around them.

7.0 References - Published Research and Dissemination

FIRE partnerships with organizations like the Boy Scouts, 4H, the Robotics Educational Foundation, FIRST Robotics, Robomatter, and BEST Robotics have enabled the CMRA/DARPA partnership to make a significant difference in the lives of hundreds of thousands of children. The three biggest enables of CS-STEM literacy are: the curriculum which is available on line at no charge, the Robot Virtual World software (RVW) which CMRA makes available at no charge each summer for training purposes, and the Expedition Atlantis math/computer science game which shows other developers how to foreground an academic concept in a robotics context. Directly below is the FIRE Projects published research and presentations:

Teaching Programming through Robotics

1. Liu, A., Schunn, C. D., Flot, J., & Shoop, R. (2013) *The role of physicality in rich programming environments.*. Computer Science Education, 23(4), 315-331., [PDF]
2. Flot, J., Shoop, R (November 2013) *Foregrounding Math, Engineering, and Computer Science using Robotics.*. Presentation given at the Technology Education and Engineering Association of Pennsylvania Annual Conference, Camp Hill Pennsylvania., [PDF copy of PowerPoint]
3. Flot, J., Shoop, R (November 2013) *Teaching Programming with Robot Virtual Worlds.*. Presentation given at the Technology Education and Engineering Association of Pennsylvania Annual Conference, Camp Hill Pennsylvania., [PDF copy of PowerPoint]

4. Liu, A., Newsom, J., Schunn, C., Shoop, R. *Learn to program in half the time!*. *Robot Magazine ,* 49-51. [Author Proof (PDF)]
5. Soldaat, X., Friez, T., Flot, J. *Pointers and Data Structures in ROBOTC*. *Robot Magazine ,* 59-61. [Author Proof (PDF)]
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11. Shoop, R. (2011, January) Computer Science Student Network Project. Presented at the Computing Education for the 21st Century (CE21) meeting, New Orleans [Handout]
12. Higashi, R., Shoop, R. (2011, November) *Organizational Expectations* Presented to Propel School System Teachers and Administrators, Robot Algebra Partnership Kickoff [Handout]

Badges, Motivation, and Assessment

1. Abramovich, S., Schunn, C.D., Higashi, R. (2013) *Are Badges Useful in Education?: it depends upon the type of badge and expertise of Learner*. Educational Technology Research & Development, March 2013. DOI: 10.1007/s11423-013-9289-2. [Paper PDF]
2. Higashi, R., Abramovich, S., Shoop, R., Schunn, C.D.(2012, June) *The Roles of Badges in the Computer Science Student Network*. 2012 GLS Conference [Paper PDF]
3. Abramovich, S., Higashi, R., Hunkele, T. Schunn, C.D., Shoop, R. (2011, July) *Achievement Systems to Boost Achievement Motivation*. 2011 GLS Conference [Paper PDF]

Approaches in Teaching Mathematics and Robotics

1. King, S., Stein, M., Schunn, C.D., (2012, May).*Designing Educative Guides: Reconceptualizing Teacher's Role in Teacherless Cognitive Tutor-based Robotics Instruction.*Paper presented at the 2012 annual meeting of the American Society for Engineering Education, Vancouver, BC. [Paper (PDF)]
2. Silk, E. M. (2011).*Resources for learning robots: Environments and framings connecting math in robotics*(Doctoral dissertation, University of Pittsburgh). Available from D-Scholarship at the University of Pittsburgh. (No. 8607) [Paper (PDF)] [Presentation (PDF)]
3. Silk, E. M., Higashi, R., & Schunn, C. D. (2011, June).*Resources for robot competition success: Assessing math use in grade-school-level engineering design*. Paper to be presented at theannual meetingof theAmerican Society for Engineering Education, Vancouver, BC, Canada. [Paper (PDF)] [Presentation (PDF)]
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presented at theannual meetingof theAmerican Educational Research Association, New Orleans, LA, USA. [Paper (PDF)] [Presentation (PDF)]
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8.0 CMRA FIRE/CS2N Sustainability Plan

CMRA will use the following strategies to sustain the DARPA seed funded mission:

Teacher Training – The Robotics Academy offers summer institutes each summer and online training each semester. The training generates approximately $150K after expenses per year.

Teacher Certification Tests – In 2013, $70K was generated through certification courses. These are fees that teachers pay in order to take the certification courses.

Student Certification Courses - We will develop mini-courses that teach "Computational Thinking Practices" and applied Science, Technology, Engineering, and Mathematics". The mini-courses will be 4-6 weeks in length and teach students how to program using games and Robot Virtual World (RVW) technologies. Each course will be part of a mapped badged pathway that lead to either an industry recognized certification (i.e. Certified LabVIEW Associate Developer) or to College in the High School Credit. The certification mini courses will be offered via the cloud with a live instructor and an asynchronous learning infrastructure that is supported using CS2N developed technology and infrastructure. We will offer the course through existing networks (i.e. FIRST LEGO League, cyber-schools, and virtual charter schools). The mini-courses will be available for purchase at $30 per seat and will include all the software a student will need to take the course as well as access to an instructor lead course. We are testing the curriculum, software, and CS2N infrastructure for the course this summer during our Robotics Summer of Learning Project.

Robot Virtual World Software has been licensed to Robomatter Inc. a for-profit company that is an offshoot of Carnegie Mellon's Robotics Academy. Robomatter was spun out of Carnegie Mellon's Robotics Academy in 2004 and has made its technology and IP available to the Robotics Academy at no charge. Robomatter will generate approximately $250K of revenue from sales of RVW during 2014 which will pay for full time developers and support personnel to support the software. Robomatter projects this revenue stream will increase significantly as more teachers and students become aware of the software.

Expedition Atlantis App – Currently, Expedition Atlantis is available for free for teachers to use with PCs and Macs. Robomatter paid for the development of an iPad App that will be marketed

through the Apple Store. Since we've never produced or sold Apps in the past we have no experience that allows us to predict sales figures for the near future. Having said that when we searched for Robotics Apps the Apps that were there were not very good and we expect to generate revenue from the sale of this App. We will market the App to schools and sell it at bulk pricing. (i.e. 100 annual licenses for $250). We believe that all App sales to education will need to be annual licenses because we will need to update the App as the devices update and evolve.

Ongoing Educational Research – DARPA funding has enabled the Robotics Academy to develop technologies that are ripe for emerging cloud-based educational training. The Robotics Academy will continue to seek research opportunities that enable it to refine and test these technologies.

Partnerships – The Robotics Academy will continue to seek partnerships with like-minded organizations looking to improve computer science and STEM education. One partnership involved Carnegie Innovations, a Carnegie Mellon owned for-profit company that licenses Carnegie Mellon IP globally.

9.0 Conclusions - FIRE Project Summation

Carnegie Mellon Robotics Academy's FIRE project has created incredible technology as well as produced significant research that will propel the development of CS-STEM based activities in the formal and informal education community. These technologies are finding their way into informal and formal education across the United States. Tools built during the FIRE project will continue as part of the CMRA outreach. Additionally, CMRA will continue to use the technology developed by the FIRE project to offer training, certifications, and to collect data for research. Revenue generated by this technology will help sustain Robotics Academy outreach and research and development.

10.0 Acronyms

CMRA - Carnegie Mellon Robotics Academy

CMU - Carnegie Mellon University

CSSN - Computer Science Student Network

CS-STEM -Computer Science – Science, Technology, Engineering and Mathematics

CT - Cognitive Tutor

DARPA – Defense Advanced Research Projects Agency

EA - Expedition Atlantis

FIRE - Fostering Innovation through Robotics Exploration

NSF – National Science Foundation

REC - Robotic Educator's Certification

RVW - Robot Virtual World software